A Method for Retransmission of Lost Packet in Fading Channels

BACKGROUND OF THE INVENTION

Field of the Invention

The invention concerns one kind of effective and reliable transmission technique. More precisely, it concerns with a scheme for retransmission of lost packet in correlated fading channels.

Prior Art

At present, Internet and mobile communication technology has greatly development and there is a growing trend to converge them, it requires mobile communication service, originally providing voice transmission service only, to provide data transmission service at the same time. As the correlated fading characteristic of wireless channel, data packet can be lost, so there is a problem of unreliable transmission. Reliable link layer protocol, such as Automatic Repeat Request (ARQ), is one kind of a method to solve reliable transmission in unreliable transmission system.

ARQ methods can be roughly classified into Stop-and-Wait (SW), Go-back-N (GN) and Selective Repeat (SR). Among them, SR-ARQ is most efficient and has been widely used in practical mobile system, for example IS-99 (TIA/EIA/IS-99, "Data Services Option Standard for Wideband Spread Spectrum Digital Cellular System", 1955).

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Figure 1 shows a working procedure of Selective Repeat (SR-ARQ). When the receiver sends back the Acknowledge (ACK) or Negative Acknowledge (NACK), the transmitter determines whether a specific data packet (for example #1) is lost or not, and makes the selective retransmission further. When the transmitter receives an ACK signal, it means the #1 packet has been received successfully, it is unnecessary to retransmit again. When the Transmitter receives a NACK signal, it means that the #l packet has not been received successfully, it is a transmission failure, the packet is lost and it is necessary to retransmit. When retransmission, each time only one copy of the lost #l packet is retransmitted. The figure shows that after two times retransmission of #l packet copy, it is received successfully. This means that in the traditional SR-ARQ scheme, when a packet is lost, only one copy of the lost packet is retransmitted each time. Obviously, the worse environment of transmission, more times of retransmission are needed. In this case the data packet has longer persistence time in the transmitter buffer, it will seriously decrease quality of data service.

Naturally, when a data packet is lost, multiple copies of the lost data packet can be retransmitted each time. But in mobile communication system, because of the instinctive burst error characteristics in correlated fading channels, on the one hand it leads data packets are successively lost; on the other hand it is happened that, multiple copies of each retransmission will meet the bad state of the fading channels at the same time, the

retransmission is failure, i.e. retransmission efficiency is low. Therefore, in correlated fading channels how to decrease number of retransmission and to increase retransmission efficiency are two big problems needed to be considered at the same time.

SUMMARY OF THE INVENTION

It is an object of the invention to provide a retransmission method for lost packets in correlated fading channels, it will decrease number of retransmission and increase each retransmission efficiency at the same time in correlated fading channels.

The above and other objects of the invention are implemented as follows. A retransmission method for lost packet in a fading channel is characterized in that: when the transmitter receives from a receiver of a mobile communications system a negative acknowledgement (NACK), which points to a specific data packet, multiple copies of the specific data packet will be retransmitted in the way that between two consecutive copies a delay is inserted.

The multiple copies, the number of multiple copies is acquired by calculation based on the number of current retransmission of the specific data packet, it is also increased along with the increase of number of retransmission.

In on embodiment, the method of the present invention used to retransmit lost packets in fading channel, comprises the following steps:

A. At least two queues are set in the transmitter, including transmission queue and

retransmission queue;

B. New data packets, which will be transmitted, are stored in the transmission queue; the copies, the number of which are defined by current number of retransmission data packets, are stored in the retransmission queue;

C. It is determined whether the retransmission queue is in the state of empty or not, when the current retransmission queue is empty, with first-in-first-out principle, data packets in transmission queue are transmitted; When the current retransmission queue is not empty, the data packet copies in retransmission queue are transmitted with interleaving transmission;

D. The minimum value of time length of interleaving retransmission interval is set by a timer, select one copy of every retransmission data packet from retransmission queue, transmit them in every interleaving retransmission interval by the first-in-first-out principle; if before the end of minimum value of interleaving retransmission interval time length, one copy of all data packets in retransmission queue has been transmitted, then with first-in-first-out principle, data packets in transmission queue are transmitted until the end of minimum value, set by timer, of the interleaving retransmission interval time length. Then this interleaving retransmission interval will be ended and next one will be started; if before the end of minimum value of interleaving retransmission interval time length, one copy of all data packets in retransmission queue has been transmitted and the transmission queue is empty, then transmission stops

until the end of minimum value, set by timer, of the interleaving retransmission interval time length. Then, this interleaving retransmission interval will be ended and next one will be started; when an interleaving retransmission interval is ended and the retransmission queue is empty, then data packets in transmission queue are transmitted by first-in-first-out principle.

In another embodiment the method of the invention used to retransmit lost packet in fading channel comprises the following steps:

A. At least two queues are set in the transmitter, including transmission queue and retransmission queue;

B. New data packets, which will be transmitted, are stored in the transmission queue; the copies, the number of which are defined by current number of retransmission data packet, are stored in the retransmission queue;

C. It is determined whether the current retransmission queue is in the state of empty or not, when the current retransmission queue is empty, with first-in- first-out principle, data packets in transmission queue are transmitted; when the current retransmission queue is not empty, the data packet copies in retransmission queue are transmitted with multiple queue polling transmission;

D. Setting copy queues with sequence number, each copy queue includes one copy of different data packet. Starting from first copy queue, with first-in- first-out principle, every data packet copy in each copy queue is transmitted in sequence.

Only after sending out all the copies in one queue, the next copy queue transmission can be started until the final copy queue. When all the copy queues are empty, then the polling transmission is ended and the transmission of the said transmission queue is started.

According to yet another embodiment the method of the invention used to retransmit lost packets in fading channel, comprises the steps in which a transceiver, in a mobile communication system, transmits a packet to a receiver or provides a plurality of copies of a special packet, when the transceiver receives information which indicates that the receiver does not receive the specific packet, the transceiver retransmits the specific packet in order at predetermined interval.

In an embodiment, the method of the invention used to retransmit lost packet in fading channel, is a retransmission method with multiple copies plus delay. With transmitting multiple copies of lost data packet for each retransmission, it is different with the traditional SR-ARQ, in their only one copy is sent, therefore the success probability of each retransmission is increase. At the same time, an adequate delay is inserted between two consecutive copies of the same lost data packet when transmitting multiple copies of a specific lost data packet. In this way the probability, meeting in the bad state of the fading channel for multiple copies of one lost packet, is decrease, i. e. success probability of each retransmission is increase. Therefore efficiency of retransmission is increase effectively

and number of retransmission is decrease.

Following combines embodiment and appended figures to further describe technology of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a schematic diagram of typical SR-ARQ working procedure;

Figure 2 is a diagram to define copy number of each retransmission with linear increasing scheme according to the invention;

Figure 3 is a diagram to define copy number of each retransmission with exponential increasing scheme according to the invention;

Figure 4 is a schematic diagram of interleaving procedure within interleaving retransmission scheme according to the invention;

Figure 5 is a diagram, which is the first implementing procedure for interleaving retransmission scheme according to the invention;

Figure 6 is a diagram, which is the second implementing procedure for interleaving retransmission scheme according to the invention;

Figure 7 is an analysis diagram of effectiveness for interleaving retransmission scheme according to the invention;

Figures 8 - 10 shows the emulated relationship curve diagrams between Delay Time with Effective Throughput, Delay Time with Mean of Number of Retransmissions and Delay Time with Variation of Number of Retransmissions, respectively; and

Figure 11 shows the emulated curve diagram of the improvement of transmission performance after using the invention scheme.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Figure 1 has been mentioned above, it would not be repeated.

Referring to figure 2 and figure 3, these figures show two schemes of the invention respectively, which define the specific number of lost data copies for each retransmission. They include linear increase scheme, as shown in figure 2, and exponential increase scheme, as shown in figure 3, they are all related to the number of retransmission of this (current) time.

Linear increase scheme can be summarized as the copies number for i^{th} retransmission is i+1. Exponential increase scheme can be summarized as the copies number for i^{th} retransmission is 2^i.

In figure 2, when transmitter receives NACK signal at the first time for # number data packet, it retransmits two copies of # number data packet, and inserts a delay d between two consecutive copies of each # number data packet. When transmitter receives NACK signal at the second time for # number data packet, it retransmits three copies of # number data packet, and inserts a delay d between two consecutive copies of each # number data

packet; and so on. If transmitter receives NACK signal at the third time for # number data packet, it will retransmit four copies of # number data packet, and will insert a delay d between two consecutive copies of each # number data packet (this has not been shown in the figure). Figure 2 shows at the second time of retransmission, its third copy is received correctly.

In figure 3, when transmitter receives NACK signal at the first time for # number data packet, it retransmits two copies of # number data packet, and inserts a delay d between two consecutive copies of each # number data packet. When transmitter receives NACK signal at the second time for # number data packet, it retransmits four copies of # number data packet, and inserts a delay d between two consecutive copies of each # number data packet; and so on. If transmitter receives NACK signal at the third time for # number data packet, it will retransmit eight copies of # number data packet, and will insert a delay d between two consecutive copies of each # number data packet (this has not been shown in the figure). Figure 3 shows at the second time of retransmission, its third copy is received correctly.

Obviously, for exponential increase scheme the copy number is increased rapidly along with the retransmission numbers increase, therefore efficiency is lower, but it will be returned with decrease of retransmission numbers and persistence time. It is more adequate for the environment where channel condition is very bad and the propagation

time is longer.

It is need to illustrate that the delay d, which concerns about delay between two consecutive copies above, should be a random variable. In principle, the delay should be longer than the burst channel fading period length. But it cannot be too long, because too long will increase transmitting time of data packet and decrease SR-ARQ performance. Nevertheless, for time-vary channel it is a very difficult issue to define random burst channel fading period length.

Referring to figure 4, it shows the method of interleaving procedure according to the invention, which is used to solve problem about inserting delay between every copy of same lost data packet. Before interleaving, there are 3 copies, &1, &l, &l, of #l data packet, 2 copies, &2 &2, of #2 data packet and 2 copies, &3 &3, of #3 data packet queuing in sequence in the queue. There is no delay between copies of same data packet, the sending principle is first-in-first-out. After interleaving, between every & copy of same #number data packet, one copy of two other #number data packets is inserted. For example, between every two copies of &l, a copy &2 and a copy &3, two copies in total, are inserted, between two copies of &2, a copy &3 and a copy &l, two copies in total, are insert, between every two copies of &3, a copy &1 and a copy &2, two copies in total, are inserted. It is formed that the delay time is 3, between every copy of same data packet.

In principle the interleaving method of the present invention is same as the interleaving method in channel coding, but in the present invention the interleaving object is data packets and not bits, furthermore only the multiple copies of the retransmitted lost data packet are interleaved, and the interleaving is before retransmission. It is interleaving transmission. Figure 4 shows after interl eaving, multiple copies, belong to same lost data packet, are transmitted in sequence after delay. The delay time is the time length of the number of different sequence number data packets queuing in the interleaving queue. If the burst channel fading period length is long, then the number of different sequence number data packets queuing in the interleaving queue is more and the delay is longer.

Figure 5 shows the first embodiment for the scheme of interleaving retransmission in the invention. The transmitter needs to set three queues, including transmission queue, retransmission queue and buffer queue. The transmission queue, marked with #, is used to store new transmitting data packets. The retransmission queue, marked with &, is used to store multiple copies of specific data packets needed to be retransmitted. The buffer queue, which is not belong to the scheme of the invention, is used to store the data packets having been transmitted but without receiving the acknowledgement signal. Suppose that #6, #7 and #8 are arranged in sequence from queue head in the transmission queue. In retransmission queue there are arranged in sequence with two copies, &1, &l, of #l data packet, two copies, &2, &2, of #2 data packet, and three copies, &3, &3, &3, of #3 data packet. It is known from the retransmission queue that the number of different

retransmitted packets is 3. In retransmission queue, the number of same data packet copies is acquired, first according to the current retransmission number then calculating with the linear increase principle or exponential increase principle, all the copies of same data packet are stored continuously.

In step 1, at first it is necessary to determine whether the retransmission queue is empty or not; if the retransmission queue is empty, every data packet in transmission queue is transmitted according to the first-in-first--out principle; if the retransmission queue is not empty, then it enters interleaving transmission state.

Entering interleaving transmission state is implemented by setting the length of interleaving retransmission interval. In order to control the minimum value of multiple copies transmission delay for specific data packet, the minimum value d_s of interleaving retransmission interval length should be set (it can be determined by specific mobile communication system). In the figure, two conditions are set, they are $d_s = 5$ and $d_s = 1$, respectively. The length of interleaving retransmission interval is a value should choose the largest one among the minimum value (d_s) of interleaving retransmission interval length and the maximum value of number (in the figure example it is 3) of different data packets in retransmission queue.

In step 2, interleaving transmission is proceeded, it is started to form every interleaving

retransmission interval.

When $d_s = 5$, the timer is set to 5. From the retransmission queue, one copy of every retransmission data packet is selected, &1, &2 and &3, and they are transmitted by the first-in-first-out principle. When the transmission is finished, the timer is not over, so data packets #6 and #7, in the transmission queue, are transmitted by the first-in-first-out principle, until the timer is over, the first interleaving retransmission interval is ended. At this moment, retransmission queue is not empty, the next interleaving retransmission interval is started. Again, from the retransmission queue, one copy of every retransmission data packet is selected, &1, &2 and &3, and they are transmitted by the first-in-first-out principle. When the transmission is finished, the timer is not over, so continuously data packet #8, in the transmission queue, is transmitted; when it is finished, the timer is not over, so stop transmission until the timer is over, the second interleaving retransmission interval is ended. At this moment, retransmission queue is still not empty, the next interleaving retransmission interval is started. Again, from the retransmission queue one copy of #3 data packet, &3, is selected and transmitted; when it is finished, the timer is not over and the transmission queue is empty, so stop transmission until the timer is over, the third interleaving retransmission interval is ended. As retransmission queue is empty, the interleaving transmission will be ended, with first-in-first-out principle, new data packet transmission in transmission queue is started (if there are new data packets in transmission queue).

When $d_s = 1$, the timer is set to 1. From the retransmission queue, one copy of every retransmission data packet is selected, &1, &2 and &3, and they are transmitted by the first-in-first-out principle; When the transmission is ended the timer is over, so the first interleaving retransmission interval is ended. Because the retransmission queue is not empty, the next interleaving retransmission interval is started. Again, from the retransmission queue, one copy of every retransmission data packet is selected, &1, &2 and &3, and they are transmitted by the first-in-first-out principle; when the transmission is finished, the timer is over, so the second interleaving retransmission interval is ended. At this moment, the retransmission is still not empty, so next interleaving retransmission interval is started. Again, from the retransmission queue one copy of #3 data packet, &3, is selected and transmitted; when it is finished, the timer is over, so the third interleaving retransmission interval is ended.

In step 3, when retransmission queue is empty, interleaving retransmission state is ended; with first-in-first-out principle, data packets in transmission queue are transmitted. As shown in the figure when $d_s = 1$, after the third interleaving retransmission interval is ended, it is started to transmit data packets in transmission queue, #6, #7, and #8.

Two real examples in figure 5 show that the length of interleaving retransmission interval is the retransmission delay of multiple copies of every lost packet. In reality, the length of

interleaving retransmission interval is determined by d, and the number of lost data packets; $d_s = 1$ is a special case, the length of interleaving interval is only determined by the number of successively lost packets.

With reference to figure 7, in reality, the interleaving retransmission procedure of the invention is using the number of continuously lost packets in last transmission to predicate the length of current channel fading period. In an ideal case, the length of channel fading period is unchanged, only one time of interleaving retransmission is needed, i. e. every lost data package needs to transmit only two copies.

Figure 7 shows that when the number of continuously lost packet in last transmission is 4 (#3, #4, #5, #6), the length of predicting channel fading period is 4. After one time of interleaving retransmission, that is every lost data packet only transmits two copies, &3, &4, &5, &6 and &3, &4, &5, &6, the receiver receives the retransmission data packets &3, &4, &5, &6 successfully.

Therefore, the value of the timer is decided, based on the number of continuously lost packets in last transmission or based on the measurement result of the technique by which the fading pitch is measured.

Referring to figure 6, it shows the second embodiment of the method for multiple copies plus delay retransmission scheme of the invention. It is a multiple queues polling

retransmission method. Compared with the first embodiment, shown in figure 5, the interleaving transmission method shown in fig. 6 is different.

The transmitter also needs three queues, including transmission queue, retransmission queue and buffer queue. The transmission queue is used to store new data packets to be transmitted. The retransmission queue is used to store multiple copies of every specific data packet needed to be retransmitted. The buffer queue is used to store the data packets having been transmitted but without receiving the acknowledgement signal (it is not belong to the scope of the invention scheme).

When the retransmission queue is not empty, it enters interleaving retransmission state, polling transmission is started.

Step l. Set N individual copy queues, the sequence numbers are copy queue l, copy queue2, copy queue 3, ... , copy queue i, ... , copy queue N, one copy of every specific retransmission packet will be stored in each copy queue in sequence. For example, two copies of #l retransmission data packet, &l and &1, are stored in copy queue l and copy queue 2, respectively, two copies of #2 retransmission data packet, &2 and &2, are stored after copy &l, in copy queue 1 and copy queue 2 respectively; three copies of #3 retransmission data packet, &3, &3 and &3, are store, after copy &2, in copy queue 1, copy queue 2 and copy queue 3 respectively. This means if a retransmission data packet has k

individual copies, then the k copies are stored in copy queue 1, copy queue 2, ... , copy queue k, respectively.

Step 2. Start from copy queue 1 to copy queue N, they are transmitted in sequence. Then, if any copy queue is not empty, it will start again from copy queue 1 to copy queue N transmitted in sequence until all the copy queues are empty, and the polling transmission procedure is ended. When transmitting, only after the current copy queue is empty, then the next copy queue can be transmitted. This means only when the i^{th} copy queue is empty, then the $(i + 1)^{th}$ copy queue can be transmitted. Furthermore in spite of whether there is any empty copy queue from i^{th} copy queue to N^{th} copy queue in real, it must be transmitted in sequence until the N^{th} copy queue.

Step 3. When all N individual copy queues are empty, polling transmission procedure is ended, and transmitting new data packet in transmission queue is started.

Considering that in many mobile communication systems, numbers of retransmission are controlled in real operation, for example, in IS-99, numbers of retransmission cannot exceed 3. This means that in one retransmission, the copy number will not exceed a certain fixed value. If using the linear increase method of the invention, then in one retransmission the copy number is not exceeded 4. If using the exponential increase method of the invention, then in one retransmission the copy number is not exceeded 8. When using the second embodiment the polling transmission of multiple queues, the number of copy queue

can be set respectively as 4 and 8, the implementing procedure will be greatly simplified.

Therefore, under limiting the numbers of retransmission, the effect of second kind method, polling retransmission method, is same as the first kind method with $d_s = 1$, but the implementation of polling retransmission method is more simple.

Reference is now made to figure 8, figure 9 and figure 10. Under the conditions of 20 db signal-to-noise ratio (S/N), and different channel fading speed f_d (Hz), such as 5 Hz (represented by triangle), 10 Hz (represented by lozenge) and 50 Hz (represented by *), with emulation approach, there are the result of relationship between delay time (T_{delay}) and effective throughput, delay time (T_{delay}) and mean of number of retransmissions, and delay time (T_{delay}) and variance of number of retransmissions, respectively. In figures, colored thread line represents Delay-Linear-Multiple-Copies-Retransmission scheme, dot dash line represents Delay-Exponent-Multiple-Copies-Retransmission scheme.

The figures show that slow fading speed will lead to decreased throughput, increase mean of number of retransmission and variance of number of retransmission. This is because slow fading speed has larger correlation and longer fading period length, which increase the probability of successive lost packet.

Besides, directing to the traditional Selective Retransmission (SR) scheme, the Delay-

Linear-Multiple-Copies-Retransmission (D-Linear-MCR) scheme and the Delay-Exponent- Multiple-Copies-Retransmission (D-Expo-MCR) scheme, it can further be acquired the influence of channel round trip time to effective throughput, mean of number of retransmissions and variance of number of retransmissions. The result is that: along with increased round trip time, the Delay-Multiple-Copies-Retransmission scheme of the invention will get better performance. This is because after passing a longer round trip time, the correlation of successive retransmission is decrease.

In addition, also directing to the traditional Selective Retransmission scheme, the Delay-Linear-Multiple-Copies-Retransmission scheme and the Delay-Exponent-Multiple-Copies-Retransmission scheme, with different channel fading speed (as 10 or 100Hz), it can also be acquired the influence of signal-to-noise-ratio (SNR-db) to effective throughput, mean of number of retransmissions and variance of number of retransmissions. The result is: along with the decrease of signal-to-noise-ratio, especially when the signal-to-noise-ratio is less than 25 dB, the performance of delay multiple copies retransmission is decreased greatly.

Figure 11 is a simulation curve diagram of transmission performance improvement according to the method of the invention. In a typical mobile communication system, emulating different ARQ schemes, the performance of Transfer Control Protocol (TCP) have been acquired. In emulation, the following conditions are taken:

The capacity of wired network is 100Mbps;

The capacity of wireless link is 2Mbps;

The propagation delay of wired network is 50ms;

The propagation delay of wireless network is 10ms;

The link layer packet size is 53 bytes;

The TCP packet length is 576 bytes;

The buffer in base station can store at most 384 link layer packets;

The maximum times of retransmission are 2 (copies are 3 or 4);

The minimum value of interleaving retransmission interval d_s is 1;

Two state Markovian model is used to simulate fading channel.

Figure 11 compares the end-to-end TCP throughput of different ARQ scheme. The X-axis represents channel fading speed f_d (Hz), and the Y-axis represents throughput. The dot line connected with hollow lozenge blocks, shows the ideal state without limiting numbers of retransmission (unlimited retransmission). The solid line connected with solid square blocks, shows performance of traditional selective retransmission (SR-ARQ) scheme. The solid line connected with solid lozenge blocks, shows performance of Linear-Multiple-Copies-Retransmission (Linear-MCR) scheme. The solid line connected with + symbol, shows performance of Exponent-Multiple-Copies-Retransmission (Expo-MCR) scheme. The solid line connected with solid triangle shape, shows performance of Delay-Linear-Multiple-Copies-Ret (D-Linear-MCR) scheme. The solid

line connected with * shape, shows performance of Delay-Exponent-Multiple-Copies-Retransmission (D-Expro-MCR) scheme. The results show: the invention scheme compares with traditional SR-ARQ scheme, a better TCP end-to-end throughput can be acquired. Experience also shows performance of the D-MCR scheme is better than MCR scheme, while different multiple copies schemes (Linear and ExPro) have no much difference.

In general, in the fast fading channel, because mean lost rate of data packets is higher, performance of the Exponent scheme is better than Linear scheme, throughput is large. But in the slow fading channel, longer fading period length will greatly decrease the effectiveness of multiple copies scheme, so at the lower effective throughput condition, throughput of Exponent scheme will be lower than the Linear scheme. Therefore, it should select different multiple copies scheme for different requirement.